Executive Summary

SSRL is developing a long-range plan to transfer its evolving scientific programs from the SPEAR3 light source to a much higher performing synchrotron source. The new source would have an order of magnitude higher average brightness and flux in the 1- Å wavelength range than any existing or future storage ring sources planned for the next decade around the world. This enhanced capability will enable new science and faster data acquisition while benefitting from the inherent stability of a storage ring light source. The new source would be housed in the 2.2-km PEP-II tunnel and utilize many but not all of the PEP-II accelerator components and systems. Following the PETRA-III model, PEP-X will have a hybrid lattice where two of its six arcs contain DBA (double-bend achromat) cells that provide a total of ~32 straight sections for insertion device beam lines extending up to 140 m into two new experimental halls (~125,000 sq. ft. each, including lab-office space as shown in Figure ES.1) and the remaining arcs contain TME (theoretical minimum emittance) cells. Beam lines up to 250 m can be accommodated in each hall if the source is situated at the upstream end of the adjacent 120-m long straight section. Beam lines up to 600 m could be located in the PEP arc 1 area.

Using ~90 m of damping wigglers, the horizontal emittance at a 4.5-GeV operating energy with low stored beam current is 0.09 nm-rad. The emittance coupling can be adjusted to produce a

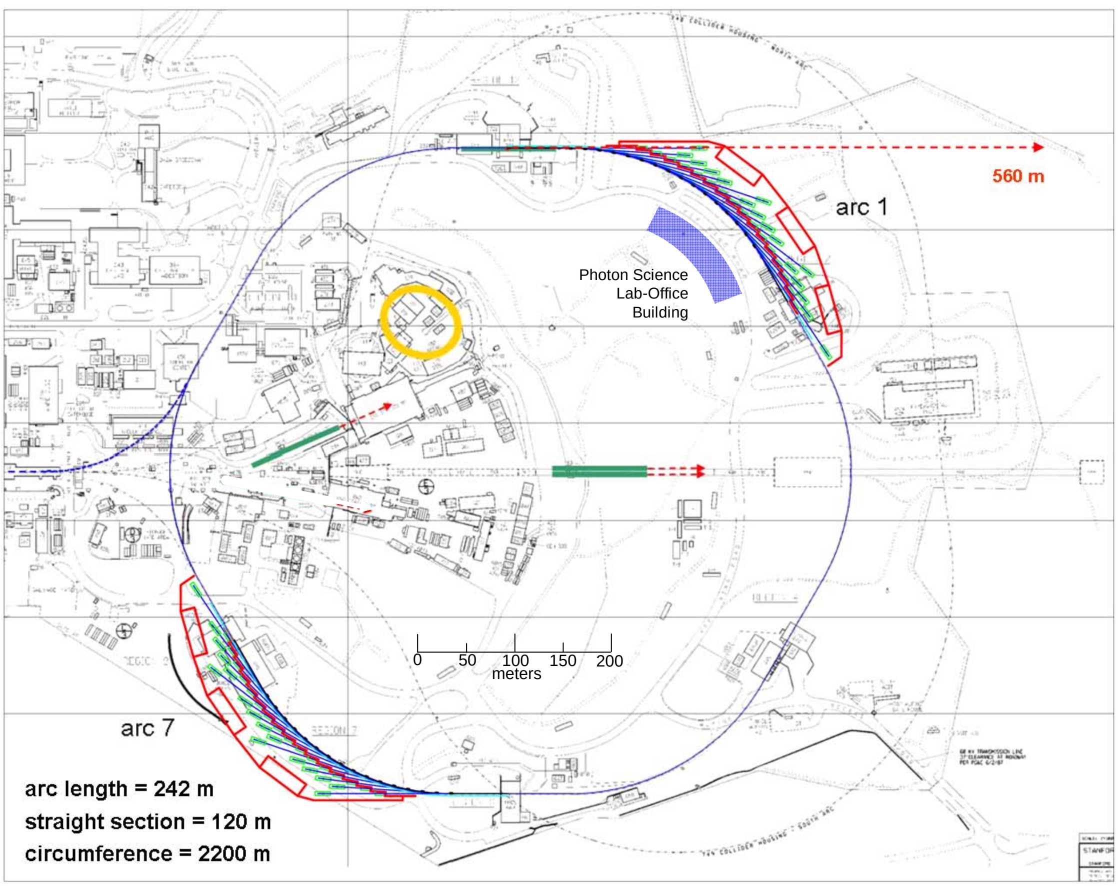

Figure ES.1: Conceptual layout of PEP-X light source with two experimental halls containing ~32 x-ray beam lines, up to 140 m long, with long beam lines (~560 m) accommodated in arc 1. SPEAR3 is shown in yellow; green rectangles represent existing and future FEL undulators for the LCLS. A future lab-office building for Photon Science is also indicated (in block form, not included in the PEP-X proposal).

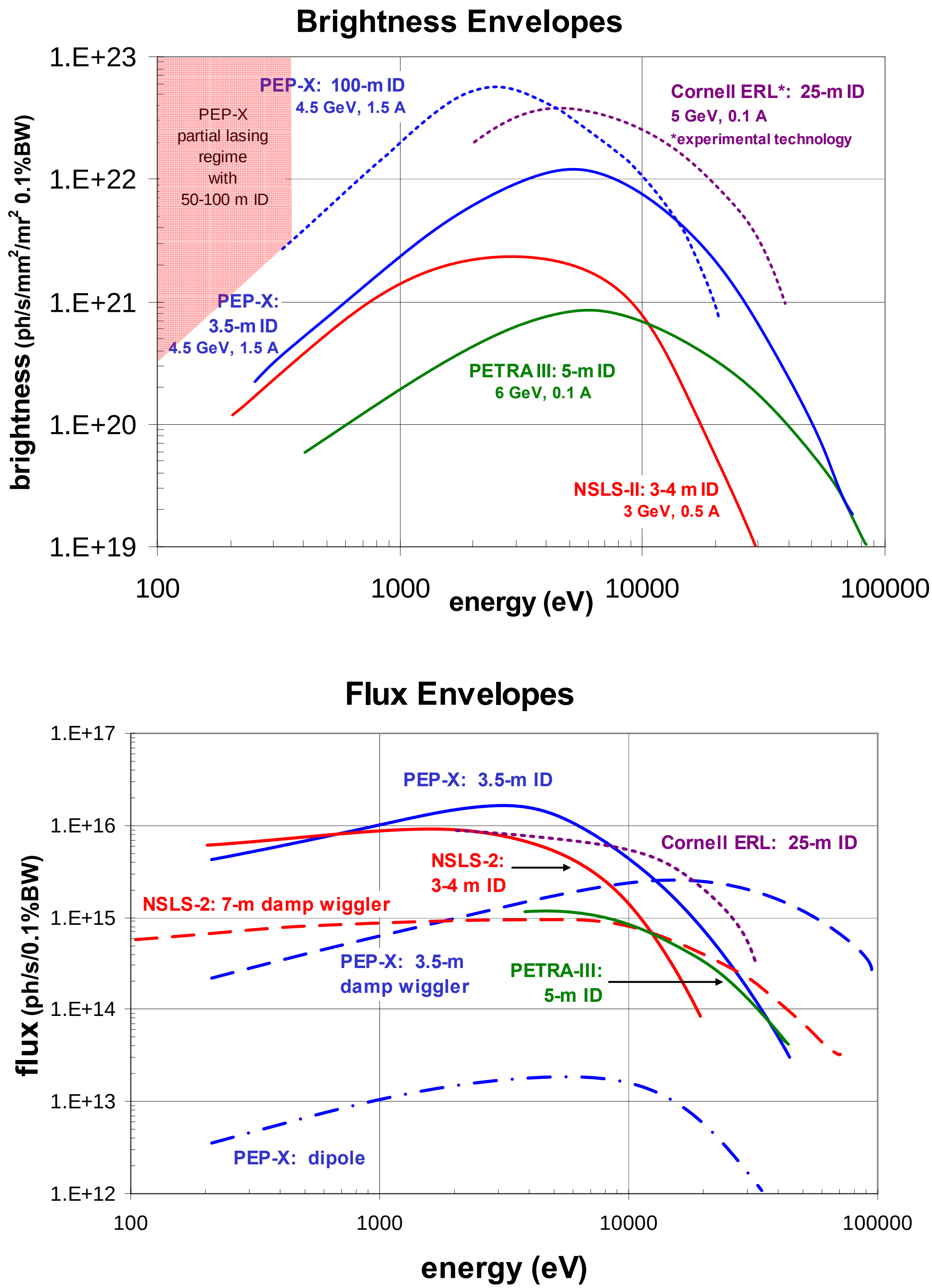

Figure ES.2: Approximate brightness and flux envelopes for PEP-X and other present and future light sources. Partial lasing in a 50 to 100-m ID may be possible at energies <360 eV, increasing brightness by one or two orders of magnitude. The envelope for the futuristic Cornell ERL [6], presently an experimental R&D project, assumes a 25-m ID operating in either high-flux mode (100 mA) or high-coherence mode (25 mA); its spectrum extends to energies higher than shown. PEP-X brightness may be enhanced by a factor of ~2 with optimized lattice parameters at ID straight sections and using high-performance IDs.

vertical emittance of 8 pm-rad, the diffraction-limited emittance for 1-Å radiation. With this coupling, the horizontal emittance grows to 0.14 nm-rad when the beam current is increased to the nominal 1.5-A operating value due to intrabeam scattering within each bunch. The emittance growth due to intrabeam scattering is a function of electron energy, becoming more significant as energy is reduced. The 4.5-GeV operating energy presently chosen in our study represents a first-order optimization of overall spectral brightness in the 1-20 keV range (Fig. ES.2) given intrabeam scattering effects (Sec. 2.6). In future studies, operating energies in the 4-5 GeV range will be more thoroughly investigated to determine if the spectral brightness envelope for this photon energy range can be more optimally balanced.

While the accelerator rf and vacuum chamber systems can operate with an electron current of up to 3 A, the operating current of 1.5 A was chosen for stable multibunch operation, minimal emittance growth due to intrabeam scattering, and to limit the angular power density from undulator sources to 1 MW/mrad^2, a value that can be handled by present-day beam line optical components situated ~50-60 m from the source. Due to the short beam lifetime at these currents (<1 hr) for small vertical coupling, frequent top-off injection, on the order of once per second(s) is necessary to maintain percent-level current constancy. A 3rd harmonic rf cavity will be used to increase the electron bunch length to improve lifetime; lifetime can be further improved by increasing the vertical coupling.

Advances in beam line optical design, including mirrors, refractive optics, monochromators, and other components will be required beyond existing technology to maximally exploit the low-emittance, high-brightness and high-power photon beams generated in PEP-X. Beam stability on the order of a micron or less between source and experiment will be required which is attainable only with advanced electron orbit and beam line stabilizing feedback systems.

Beyond the baseline brightness performance of ~10^{21}-10^{22} (ph/s/mm^2/ mrad^2/0.1% BW) using 3-4 m insertion devices, studies indicate that a 50-100-m undulator, possibly serving as a significant fraction of the damping wiggler and operating with the stored electron beam, could have FEL gain and brightness enhancement of a factor of 10-100 at soft x-ray wavelengths (> ~3.5 nm, < ~360 eV). For the shortest lasing wavelengths, the emittance must be kept below ~0.1 nm-rad and the peak bunch current must be 270 Apk (~1 mA average), values that might be reached by fully coupling the beam (Sec. 3.3), but that might be prevented by bunch instability induced by coherent synchrotron radiation (Sec. 2.7).

As is being explored for present-day storage ring light sources, rf crab cavities or other beam manipulation systems can be used to reduce bunch length in a section of the ring to the order of 1 ps or less (Sec. 4.1.10). In one extreme implementation, rf deflecting cavities might be used to exchange longitudinal and vertical electron beam emittances to produce very short bunches (<100 fs) at the expense of large vertical beam size (several millimeters).

The long-range plan for SLAC is to replace SPEAR3 with PEP-X as a light source by about 2020, with the entire SSRL program migrating to PEP-X around that time. This timescale calls for a start of conceptual design funding by 2014 or earlier.

Nominal source parameters are given in Table ES.1

Table ES.1: Machine parameters for PEP-X 2-DBA/4-TME lattice implementation.

Parameter	Value
Energy	4.5 GeV
Current (operating/max)	1.5 / 3.0 A
# Bunches	3400
Harmonic number	3492
RF frequency	476.00 MHz
Circumference	2199.32 m
Damping wiggler length/period	89.3 m / 10 cm
Horizontal emittance @ 0A/1.5A (ε_y = 8 pm-rad)	0.094 / 0.14 nm-rad
Beta at ID straight center* (x/y)	9.09 / 8.14 m
Beam size @ ID center, I = 1.5 A (x/y)	36 / 8 μm rms
Beam diverg @ ID center, I=1.5 A (x/y)	4 / 1 μrad rms
Bunch length (without/with harm cav)	2.5 / 5.0 mm rms
Lifetime @ 1.5A, ε_y = 70 / 8 pm-rad (5-mm bunch)	57 / 19 min
ID straight section length in arcs	4.3 m
# ID straights in arcs	30
Long straight section length	120 m
# Long straight section for IDs	2

* Betatron amplitudes in ID straights will be optimized for high source brightness and small horizontal beam size in on-going lattice development.

The following report summarizes the present status of the PEP-X design study. The study group has focused primarily on developing the very low storage ring magnet lattice and analyzing the associated dynamical properties of the electron such as lifetime and dynamic aperture. Preliminary analyses of photon beam properties, and the associated requirements for beam line components needed to preserve those properties, have been conducted based on the evolving electron beam parameters. Less time has been invested in the specification of engineering requirements for accelerator and beam line components; nevertheless, first-order estimates of these requirements and very preliminary implementation ideas are presented.

There are many challenging design tasks associated with achieving the design goals for the electron and photon beams for PEP-X. The primary design challenges are associated with creating a viable and workable very low-emittance accelerator lattice, reaching the requisite electron beam stability (in all dimensions, spatial, temporal and spectral) and the ability to deliver the superb properties of each high-power photon source to the user's experimental station with a minimal degradation. R&D activities to accomplish design goals include:

1. Developing a magnet lattice with optimized photon source betatron parameters that has sufficient dynamic aperture for efficient injection and adequate beam lifetime (Sec. 2).
2. Understanding the effects of coherent synchrotron radiation (CSR) on beam dynamics and developing remedies for those effects (Sec. 2.7).
3. Developing high power, high resolution beam line optical components (Sec. 4.2.5).
4. Developing photon absorber designs and geometries for high-power damping wiggler radiation.
5. Developing high performance electron and photon beam position monitor systems.

6. Developing precision electron orbit and photon beam trajectory feedback systems, including highly stable and actively stabilized accelerator and beam line components.
7. Designing an effective 3rd harmonic rf bunch-lengthening cavity system (Sec. 4.1.6).
8. Improving multibunch and rf feedback systems to act effectively when a 3rd harmonic bunch-lengthening cavity is operating.
9. Developing practical rf beam manipulation components for creating short bunches (Sec. 4.1.10).
10. Continuing studies of unseeded and seeded lasing in long soft x-ray undulators.

The combined R&D effort for these topics will involve 10-30 full-time equivalents plus material and service costs over several years. The specification, prioritization, and funding requirements for these activities will be determined in the future.

The scientific case for PEP-X is not included in this report, but will be addressed by a SLAC study group within the next year.

All electron and photon beam parameters and component implementation requirements presented in this report are subject to change and further optimization.